Effects of beam rotation in the counter-rotating permanent magnet quadrupole.

A. Drozhdin, D. Finley, V. Kashikhin, N. Solyak

Fermi National Accelerator Laboratory

P.O. Box 500, Batavia, Illinois 60510

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In one of the proposed Beam Based Alignment procedures, all quadrupoles and BPMs are suppose to be consequently aligned by 20% changing quad strength. If electron beam has offset in the aligning quadrupole, its position in the nearest upstream BPM, located in each quadrupole, will change with the strength changing. In rotational PM quadrupole the changing of the strength is provided by counter-rotating two middle sections of four sections at the angle of 30. In case of rotated sectors the matrix of quad contains non-compensated skew components that provide vertical and horizontal coupling of the beam motion. It can potentially complicate BBA algorithm. The effect of coupling motion was simulated for typical NLC lattice parameters. The result of simulations shows that difference in beam position in nearest BPM for traditional and Rotational PM quads is negligible. The traditional quads gradient is decreased to 0.8 of the nominal gradient when two middle sections of the permanent quad are counter-rotated by $\sim 26^o$ to receive the same gradient.

Effect of coupled motion in rotational permanent quadrupoles was simulated also for the FODO lattice with the parameters close to the first sector of NLC beam line. In simulations it was supposed that beam energy increases from 10 to 20 GeV and the quad gradient increases along the beam line to keep constant beta function. For calculated beam line of 16 FODO cells the quad gradient doubled from first to last magnet. The results of simulation for “non-compensated” and “compensated” beam lines with PM quadrupoles are shown in Fig. 3 and 9. In “non-compensated” beam line two middle sections in focusing and defocusing quads are rotated at same manner (+ϕ-ϕ). In this case the coupling effect growth with the length, that leads to increasing of effective vertical beam size due to beam rotation compared to the beam line of conventional quadrupoles.

In “compensated” beam line two middle sections in focusing and defocusing quads are rotated in opposite direction the (+ϕ-ϕ in defocusing quads, -ϕ+ϕ in focusing quads). This eliminates skew effect from rotational parts of quads (Fig. 9). Non-compensated coupling results less than 15% deviation in vertical beam size compared to uncoupled motion. Deviation in horizontal beam size in both cases is much smaller, because the horizontal beam emittance is two order of magnitude higher than vertical one.

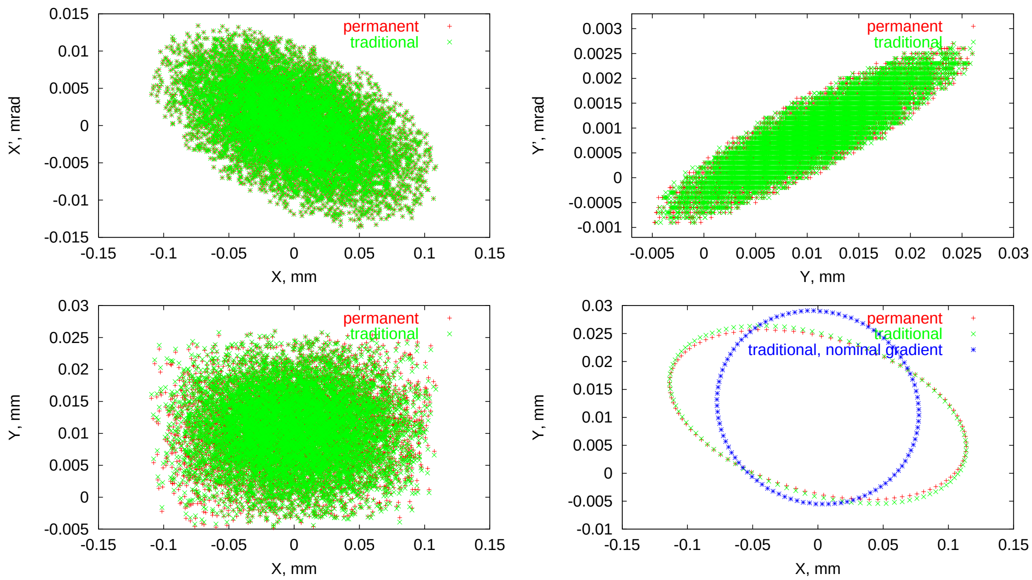

Figure 1: Horizontal (left) and vertical (right) phase space (top), and transverse space (bottom) at the second quadrupole entrance. Beam has a displacement by 0.005 mm at the first quadrupole entrance. Traditional quadrupole gradient is decreased to 0.812502 of the nominal gradient. Two middle blocks of permanent quadrupole are counter-rotated by 25.657^o. On the bottom right picture the transverse space is shown also for nominal gradient.

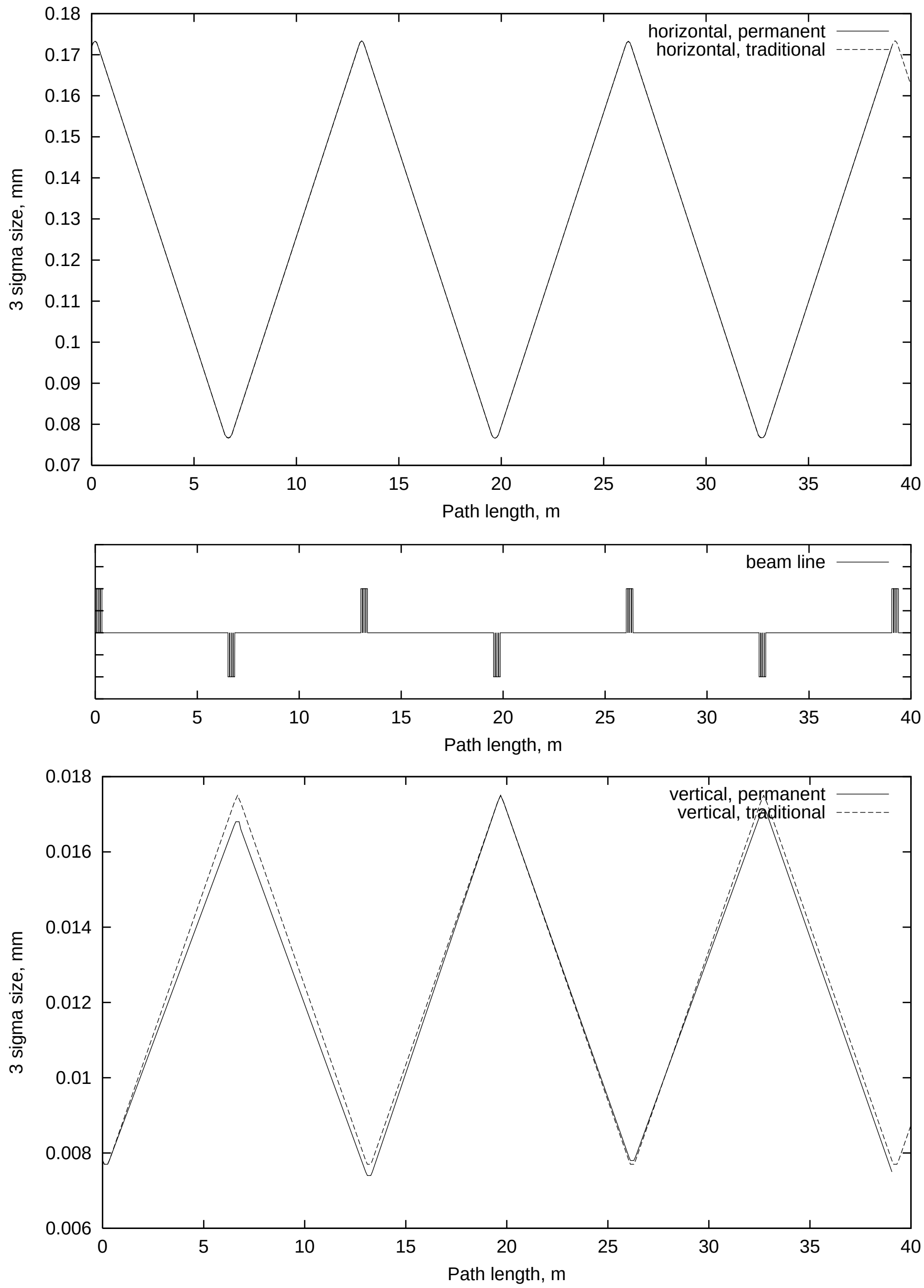

Figure 2: 3σ beam size for permanent quadrupole beam line with different sign of rotation in focusing and defocusing quadrupoles (correction), and for traditional beam line. Top - horizontal and bottom - vertical planes. Real 3 cells of NLC lattice. Calculations are done for Pc=10 GeV. The strength of permanent quadrupole reduces from 0.70621 to 0.65016 at 6 quads, angle of rotation reduces from 0.3112 to 0.1253 radian according to the particle momentum growth from 10 to 20 GeV/c at 3 cells.

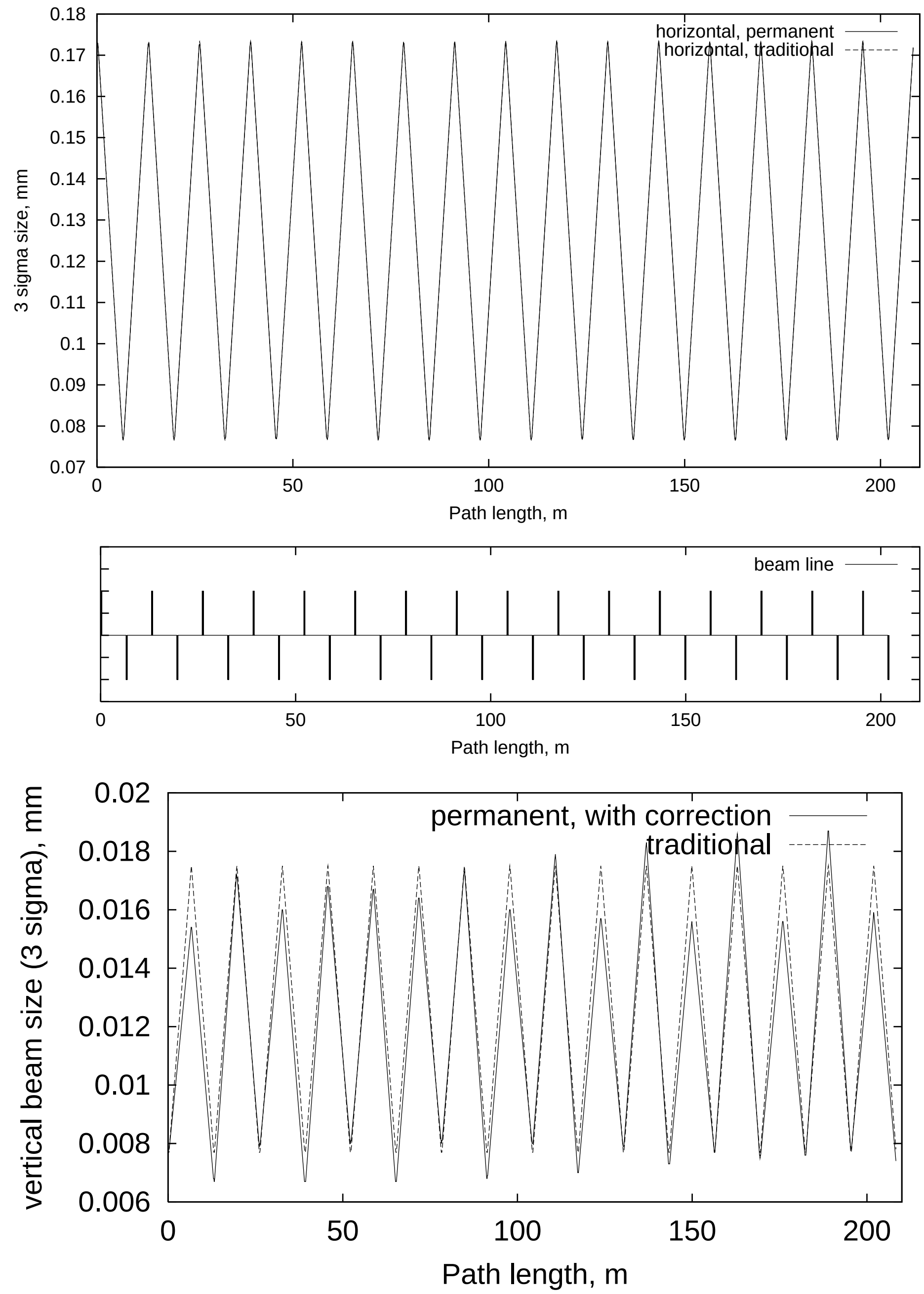

Figure 3: 3σ beam size for permanent quadrupole beam line with different sign of rotation in focusing and defocusing quadrupoles (correction), and for traditional beam line. Top - horizontal and bottom - vertical planes. Real 16 cells of NLC lattice. Calculations are done for Pc=10 GeV. The strength of permanent quadrupole reduces from 1.2800 to 0.65016 at 32 quads, angle of rotation reduces from 0.7854 to 0.1253 radian according to the particle momentum growth from 10 to 20 GeV/c at 16 cells. strength=(0.64**2)/(0.32+0.01*float(n)), cos2fi=0.02*n/0.64, angle=acos(cos2fi)/2., n increses from 0 to 31.

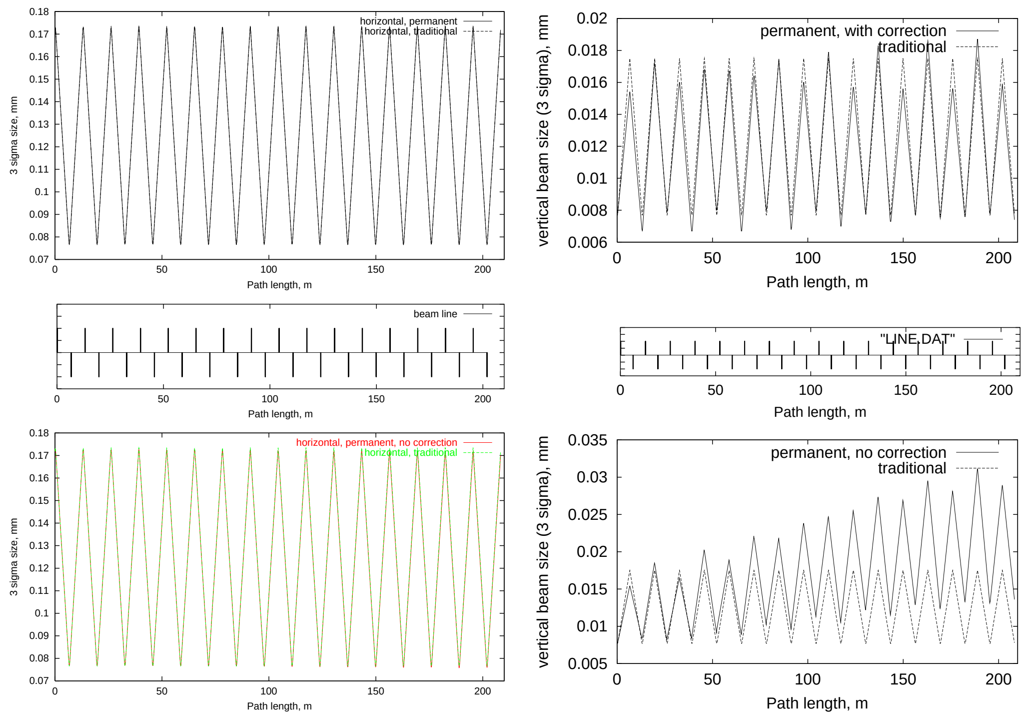

Figure 4: Horizontal (left) and vertical (right) 3σ beam size for permanent quadrupole beam line with different sign of rotation in focusing and defocusing quadrupoles (with correction) (top) and with the same sign of rotation (without correction) (bottom). Beam size for traditional quadrupoles is shown also. Real 16 cells of NLC lattice.

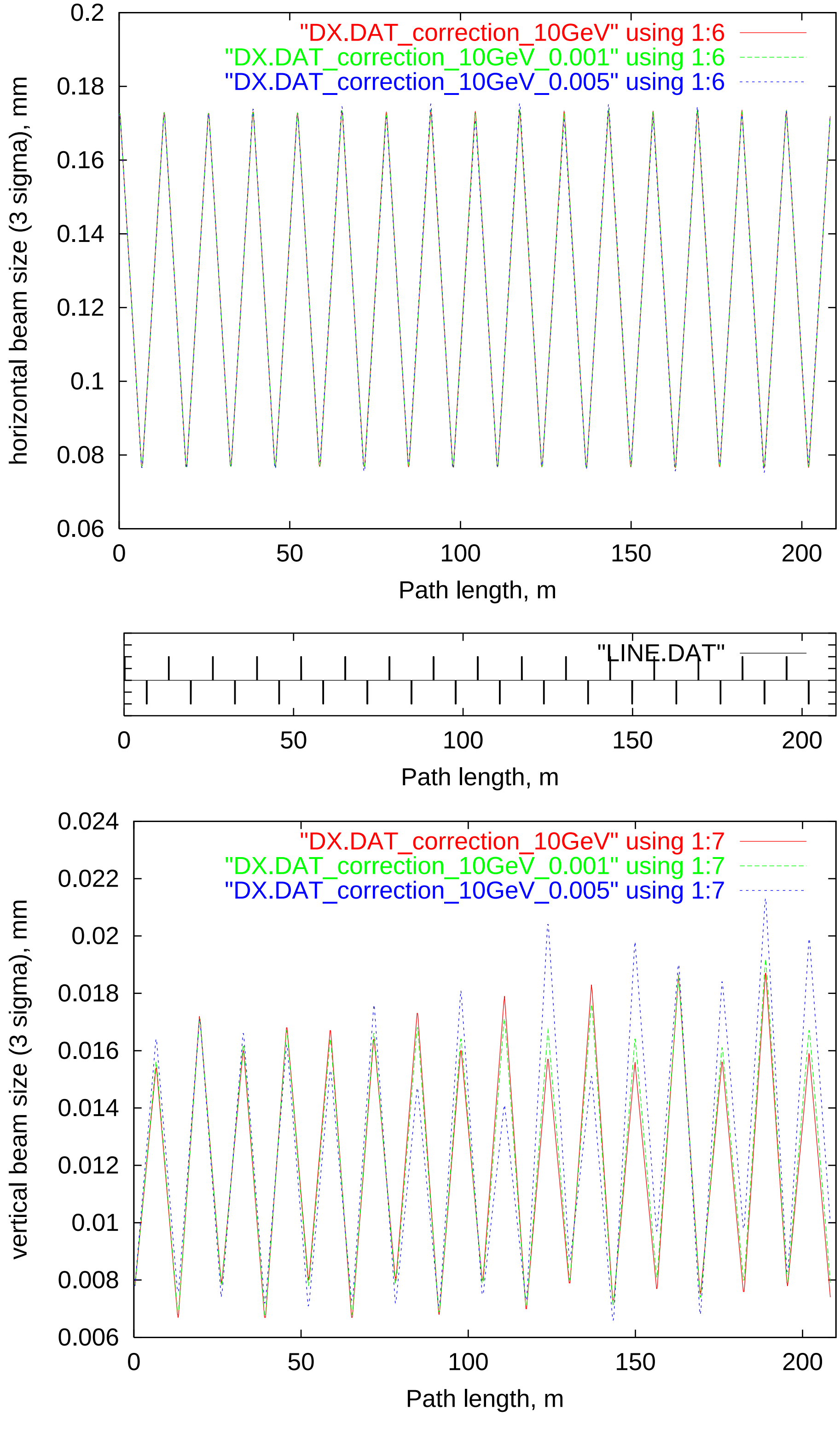

Figure 5: Horizontal (top) and vertical (bottom) 3σ beam size for permanent quadrupole beam line with different sign of rotation in focusing and defocusing quadrupoles (with correction) for additional random rotation of each quadrupole unit with $\sigma = 0.001\ radian$, $\sigma = 0.005\ radian$ and without rotation. Real 16 cells of NLC lattice.

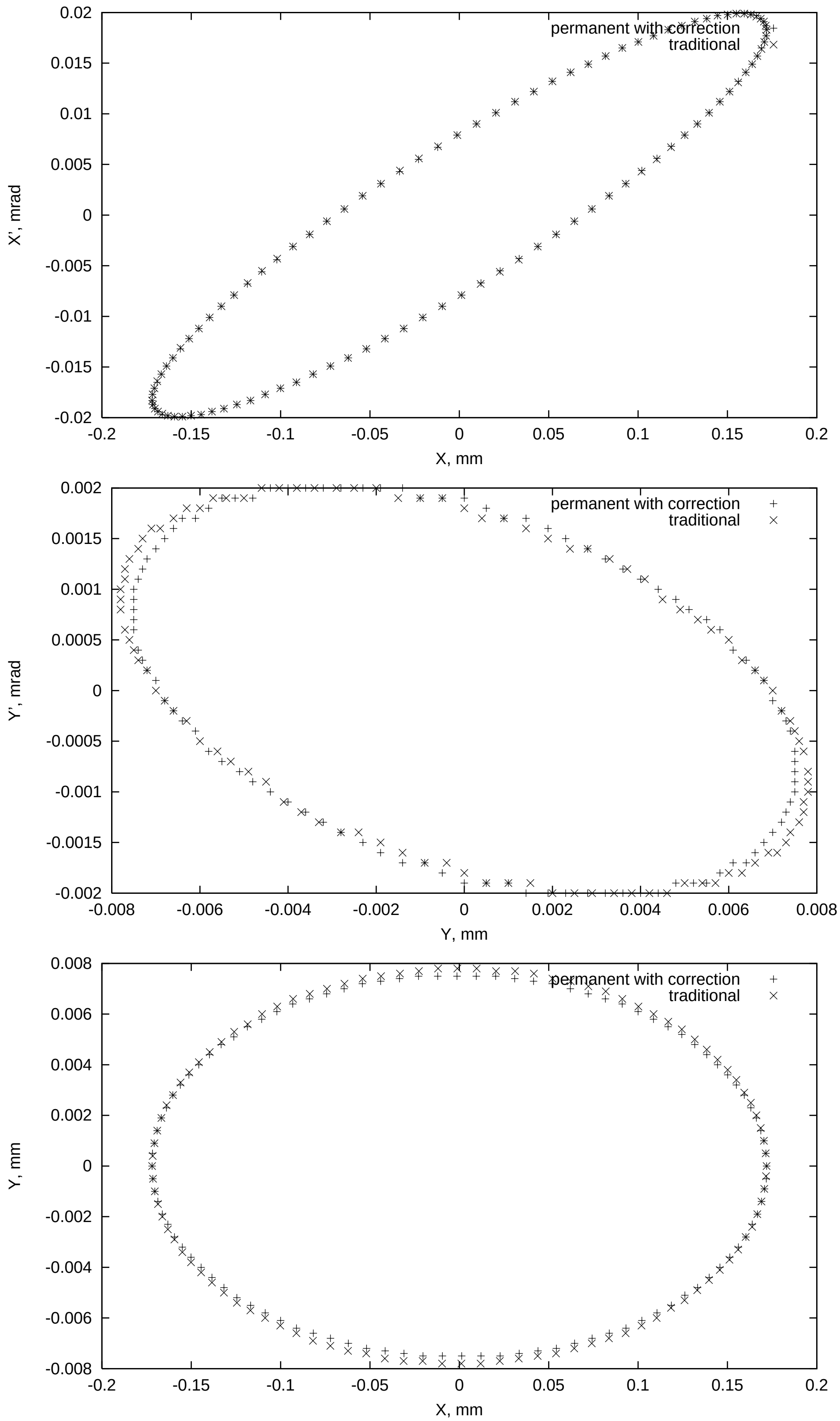

Figure 6: 3σ horizontal (top), vertical (middle) phase space and transverse space (bottom) for permanent quadrupole beam line with different sign of rotation in focusing and defocusing quadrupoles (with correction) and for traditional beam line. Real 3 cells of NLC lattice.

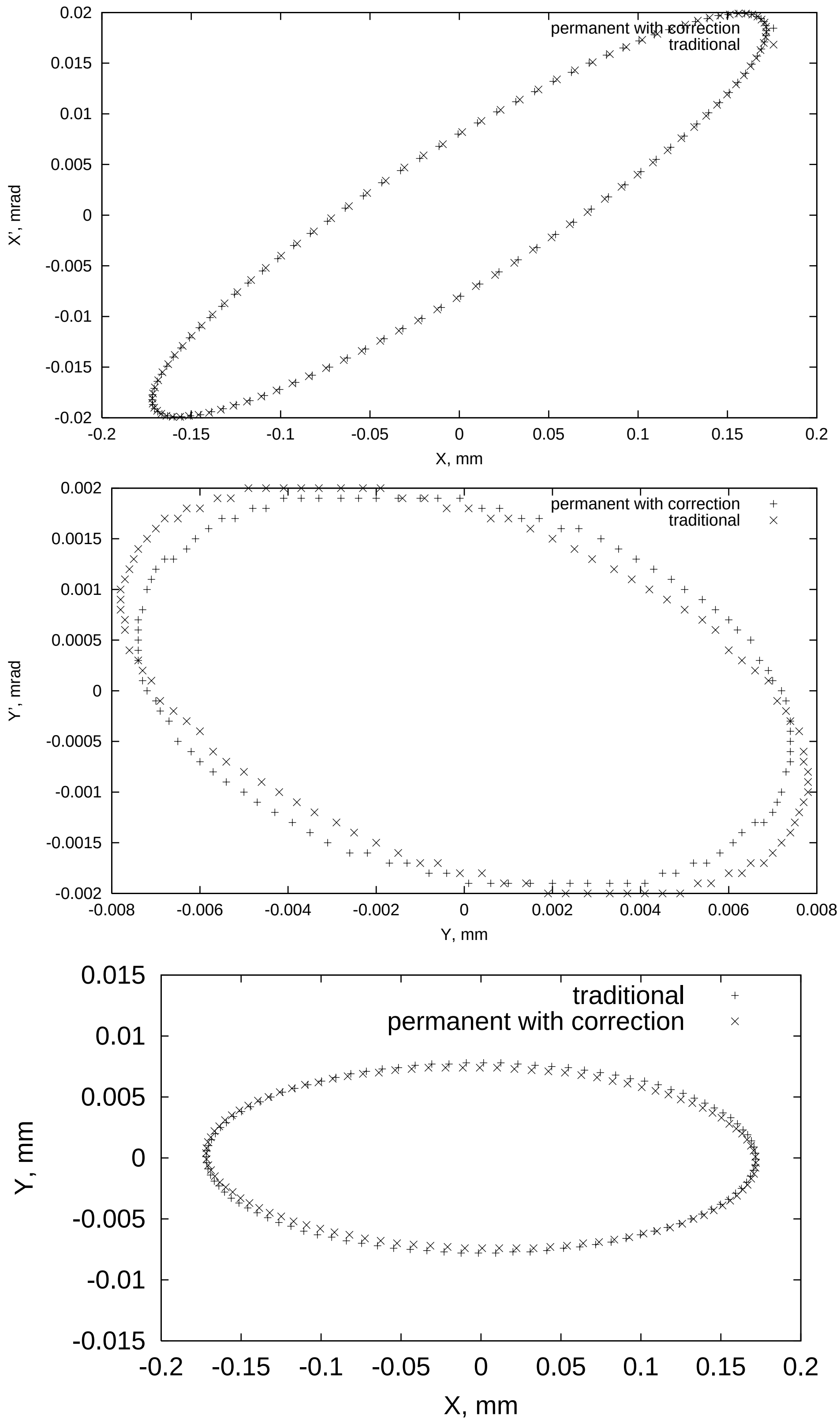

Figure 7: 3σ horizontal (top), vertical (middle) phase space and transverse space (bottom) for permanent quadrupole beam line with different sign of rotation in focusing and defocusing quadrupoles (with correction) and for traditional beam line. Real 16 cells of NLC lattice.

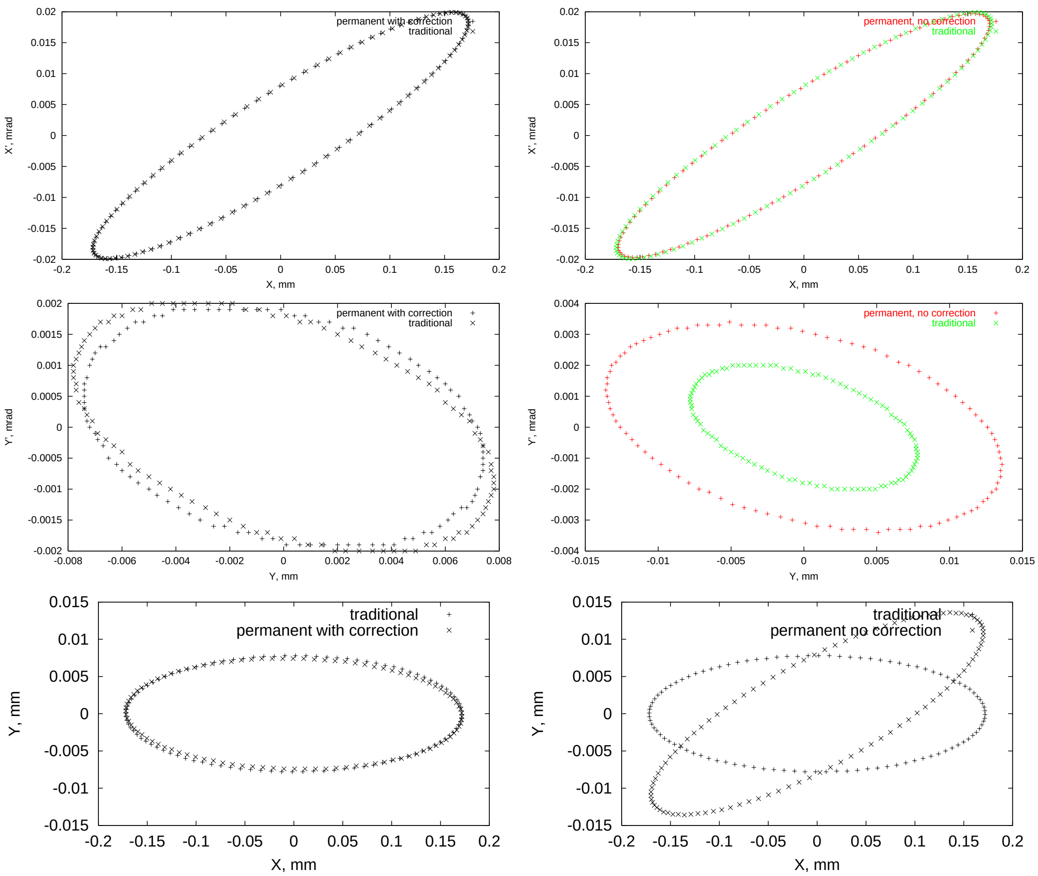

Figure 8: 3σ horizontal (top), vertical (middle) phase space and transverse space (bottom) for permanent quadrupole beam line with different sign of rotation in focusing and defocusing quadrupoles (with correction) (left) and without correction (right). Phase ellipses for traditional beam line are shown also. Real 16 cells of NLC lattice.

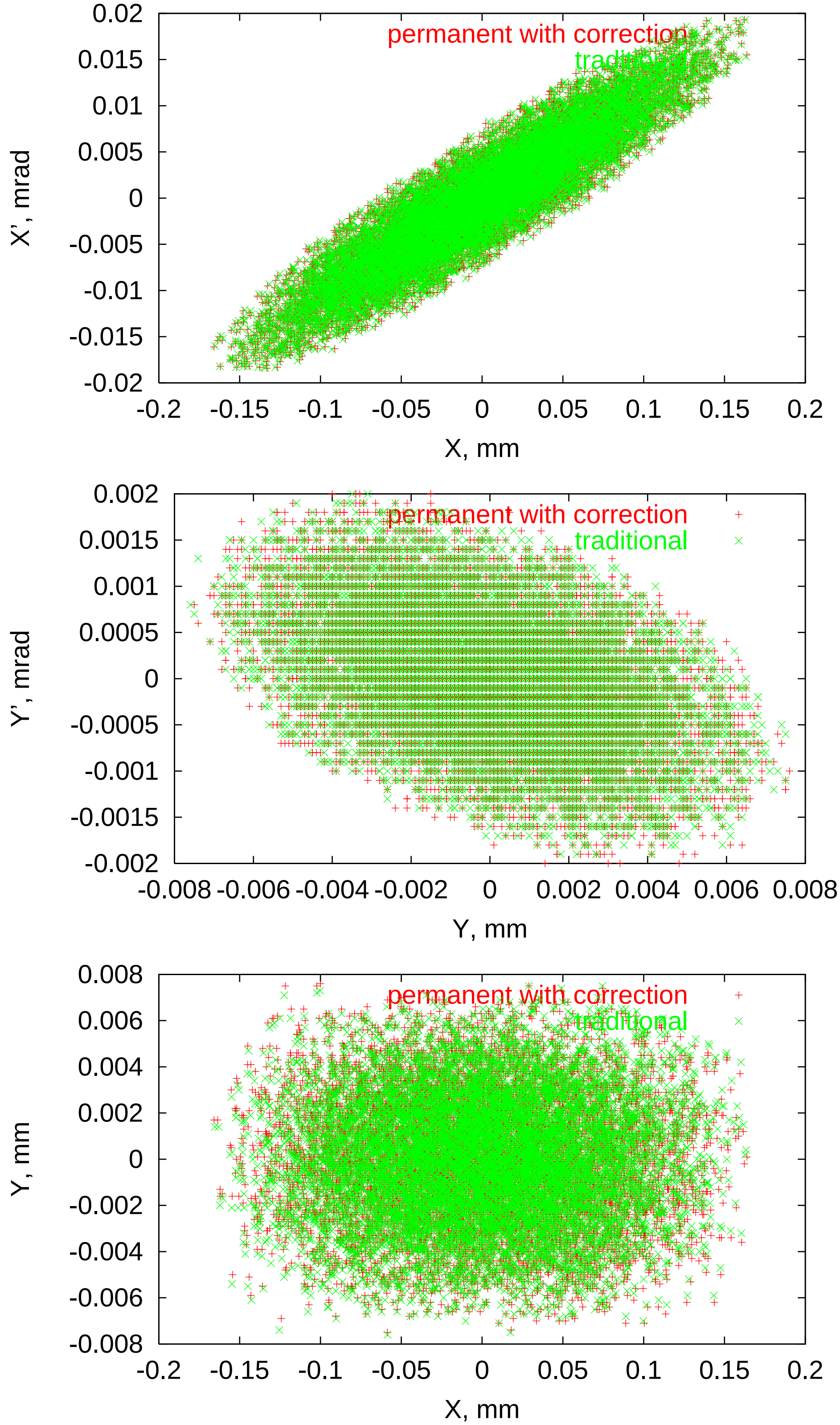

Figure 9: 3σ horizontal (top), vertical (middle) phase space and transverse space (bottom) for permanent quadrupole beam line with different sign of rotation in focusing and defocusing quadrupoles (with correction) and for traditional beam line. Real 16 cells of NLC lattice.

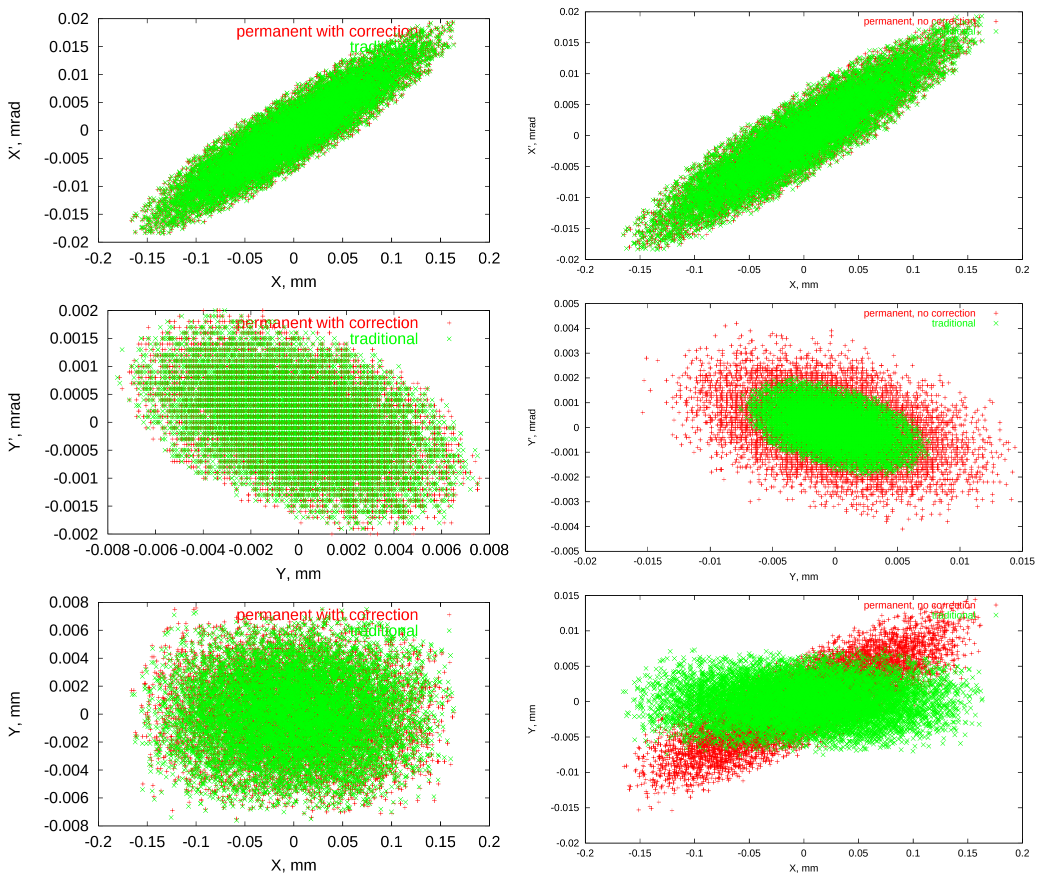

Figure 10: 3σ horizontal (top), vertical (middle) phase space and transverse space (bottom) for permanent quadrupole beam line with different sign of rotation in focusing and defocusing quadrupoles (with correction) (left) and without correction (right). Phase ellipses for traditional beam line are shown also. Real 16 cells of NLC lattice.